Announcements

- Quiz 4 due Monday, on Chapters 2 and 3
- First midterm is Wednesday Feb 19 in class
  - Will cover Lectures 1-8 and a bit of 9 (through Feb 10 + a bit of Feb 12)
  - Textbook up to Chapter 2, Light and Matter
  - Problems will be similar to those on quizzes
    - About 45 problems
    - Problems on material through Chapter 2 – includes parts of quiz 4
  - No book, notes or calculator
    - Sheet of formulas will be given
    - Calculations will be doable without a calculator
  - Review in class on Monday Feb 17

Astronomy 103

Telescopes

Chapter 3

A webcomic of romance, sarcasm, math, and language.

XKCD updates every Monday, Wednesday, and Friday.

Telescope Names

The Thirty Meter Telescope will be renamed The Flesh-Searing Eye on the Volcano.

|< | < Prev | Random | Next > | >|

Permanent link to this comic: http://xkcd.com/1294/
Image URL (for hotlinking/embedding): http://imgs.xkcd.com/comics/telescope_names.png

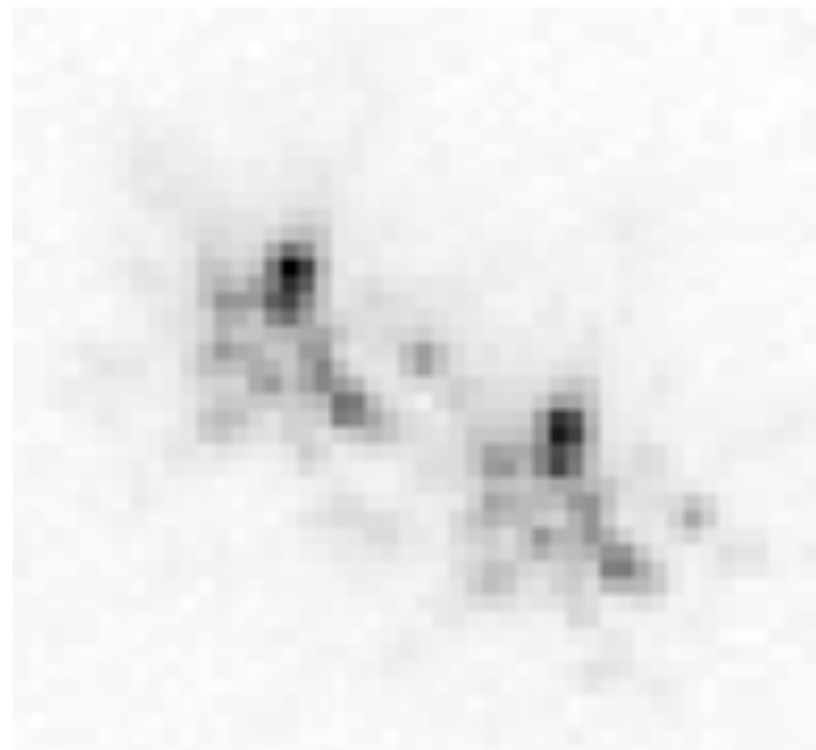
The **atmosphere** limits how clearly we can see from Earth. Ways to solve this problem:

1. Avoid it as best as possible – put telescopes on mountains
2. Get lucky
3. Fix it
4. Go to space

Get Lucky

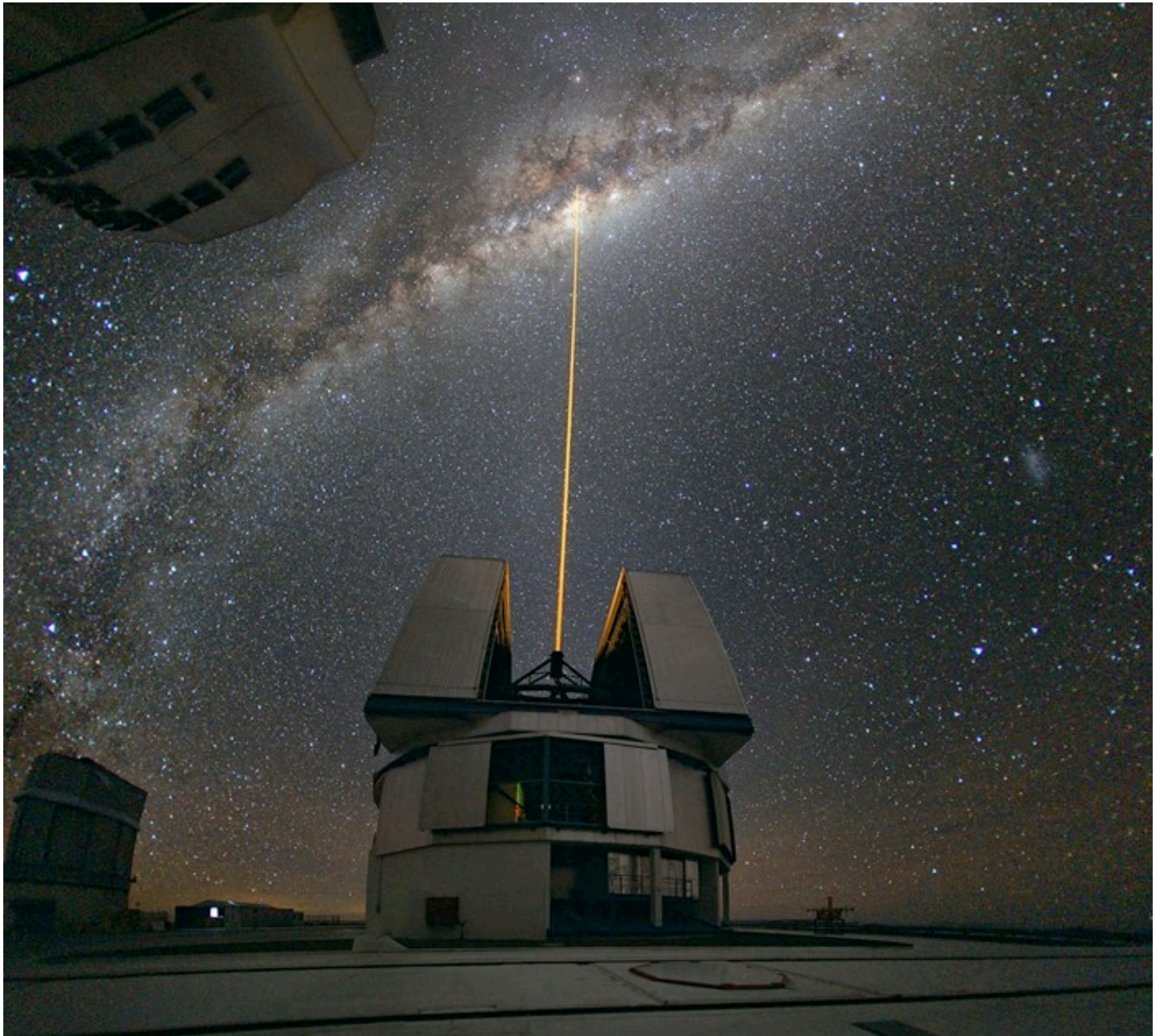
Take a video, keep only the best images, and add them up.

Lucky image



Regular image

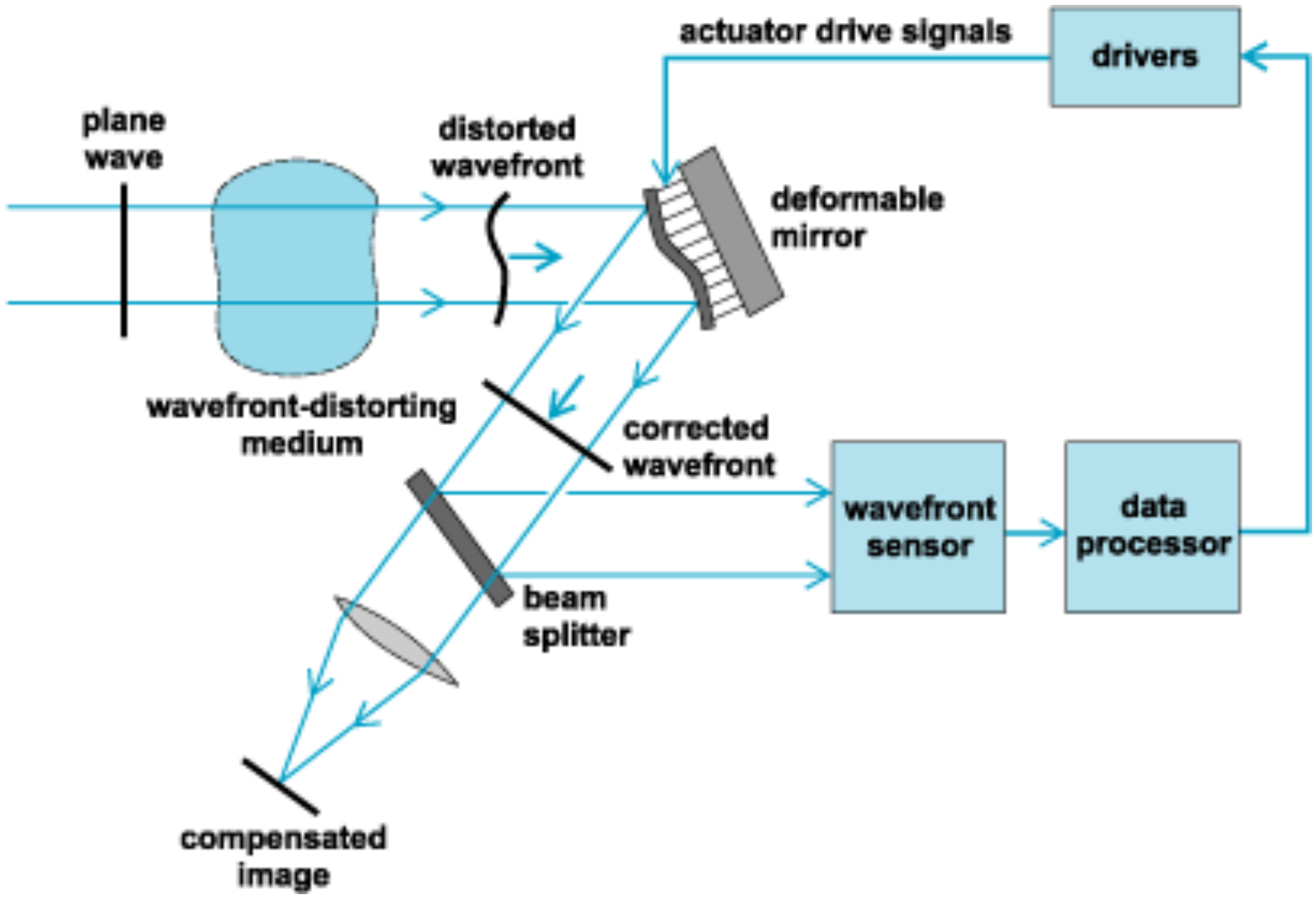
Fix it: *Adaptive Optics*



Laser excites sodium atoms in upper atmosphere to create "artificial star"

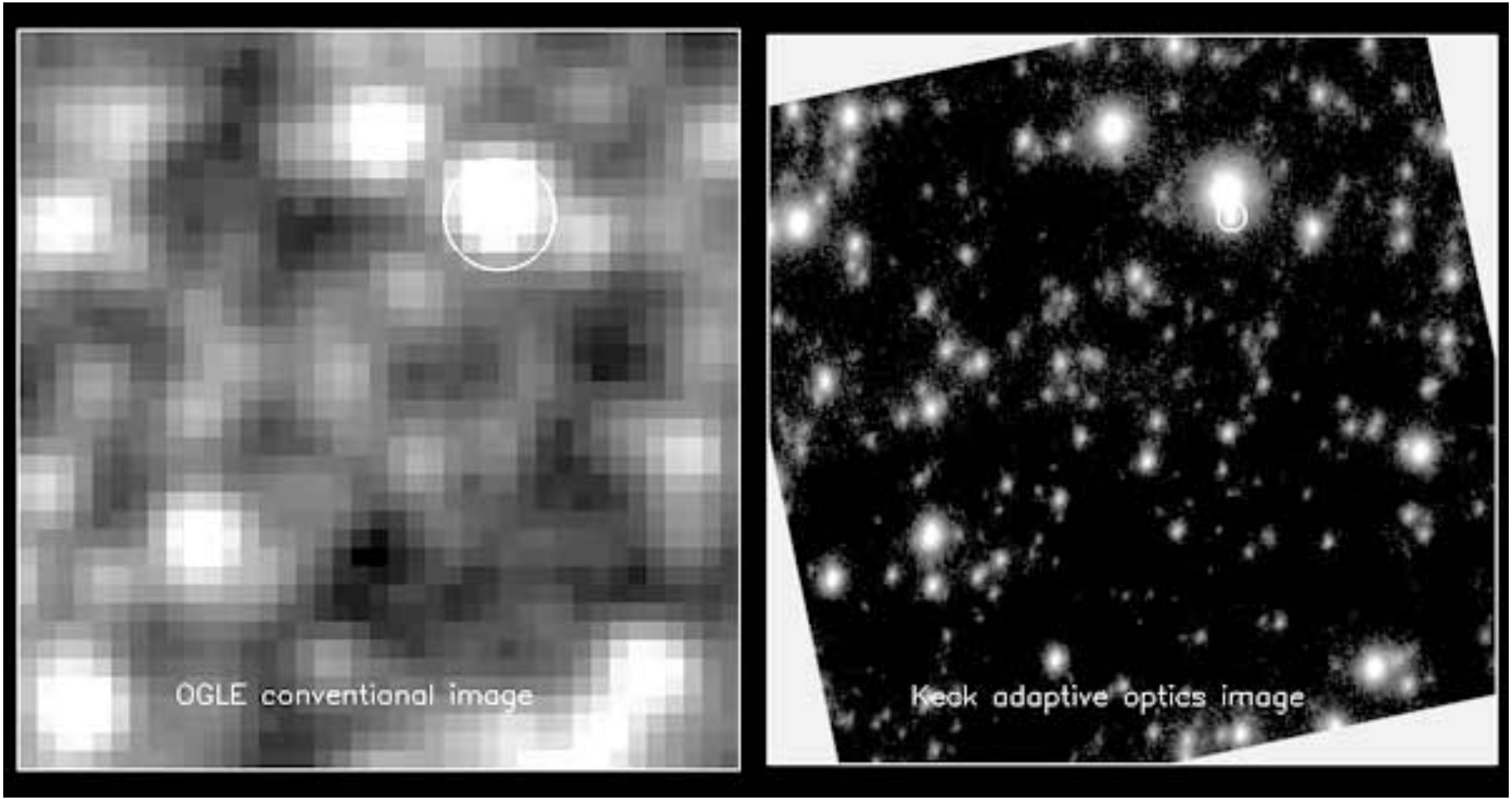
Monitor distortions of atmosphere by looking at changes in image of artificial star

Fix it: *Adaptive Optics*



Atmospheric distortions are mapped and corrected in real time (10-100 times a second) with a deformable mirror

Fix it: *Adaptive Optics*



Conventional image

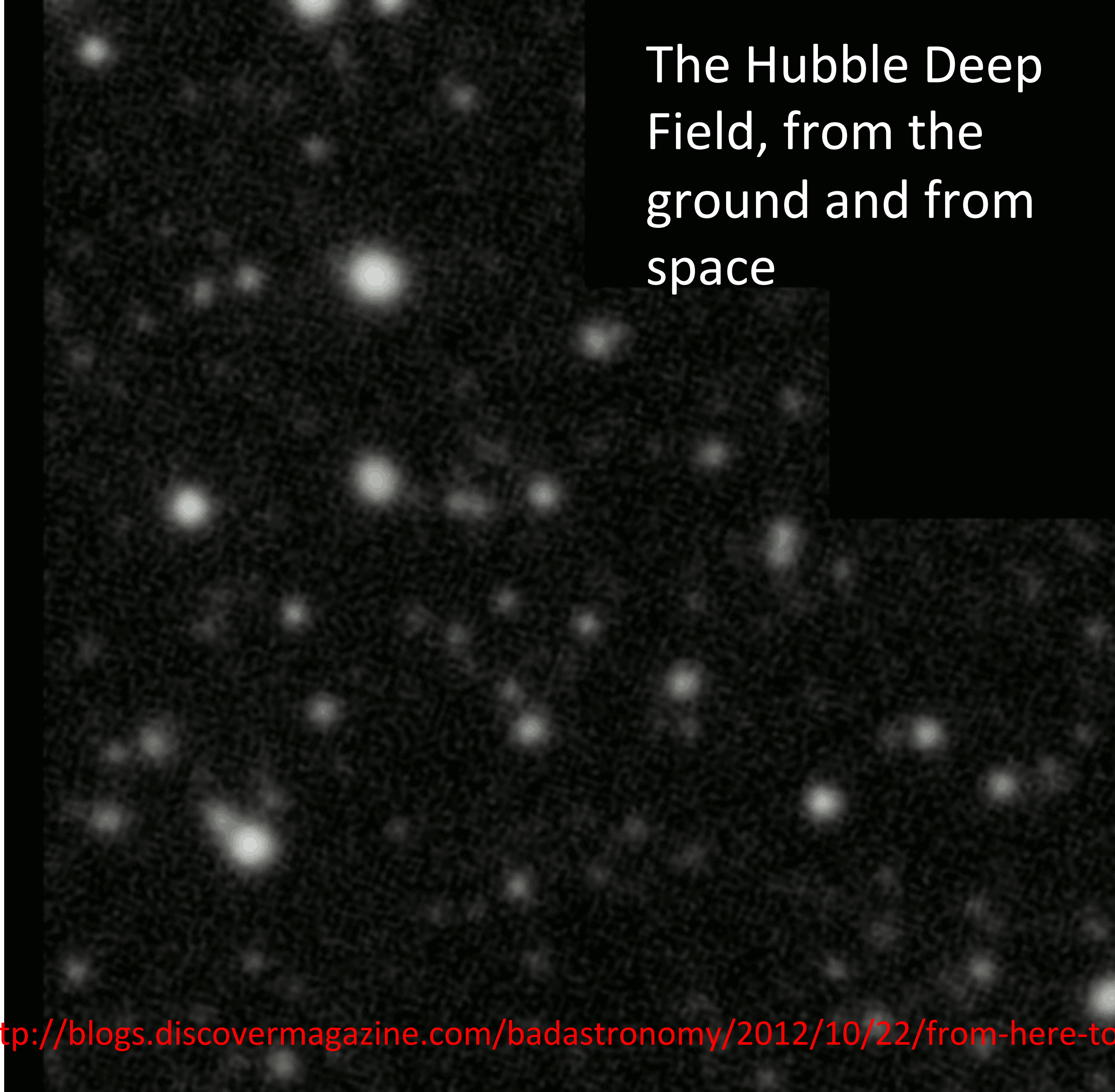
Adaptive optics image

Go to space

The Hubble Space Telescope

One of the main advantages of a telescope in space is that its images are not blurred by the atmosphere

The Hubble Deep Field, from the ground and from space



See http://blogs.discovermagazine.com/badastronomy/2012/10/22/from-here-to-infinity/

Why do we put telescopes on mountains?

A — Because the sky is usually less cloudy

B — To get closer to the stars

C — To see wavelengths of light we can’t see from sea level

D — To avoid some of the blurring effects of the atmosphere

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B — To get away from the lights of cities and other populated areas

C — To find cold, dry conditions for infrared and radio observations

D — All of the above

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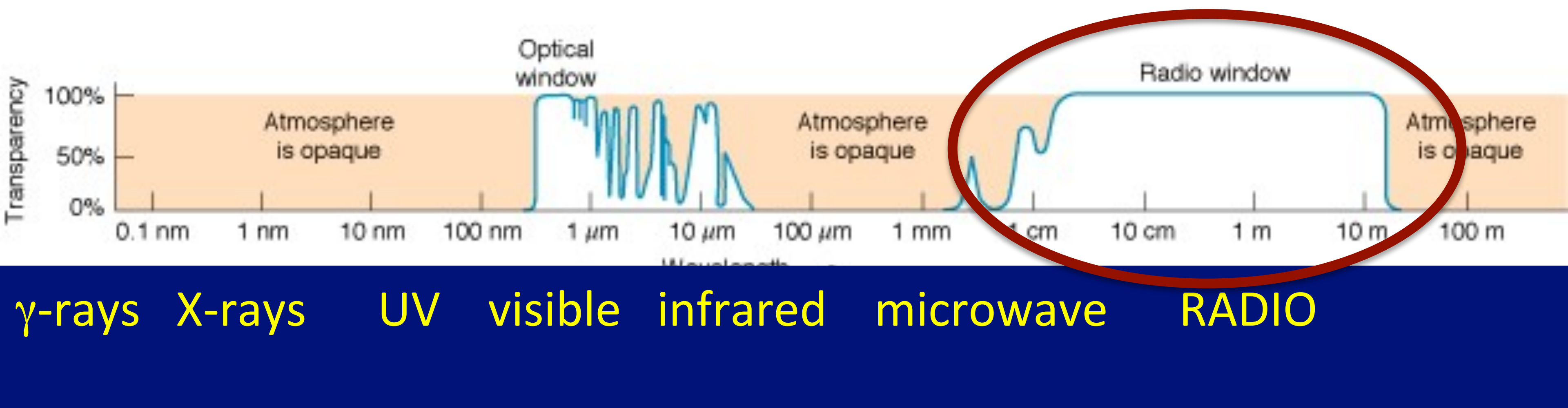
So far we have been talking about optical telescopes that observe visible light. We also observe other parts of the electromagnetic spectrum.

The atmosphere is opaque to light of most wavelengths, marked by tan shading in the diagram. **Optical** and **radio** wavelengths can be seen from the ground. For γ-rays, X-rays, most ultraviolet and most infrared light,
one uses satellite telescopes.



Radio telescopes in a nutshell

Satellite dishes are examples of small radio telescopes, focusing radio waves to a radio or TV antenna.

- A telescope mirror or dish has to be curved about as accurately as the wavelength of the light it focuses. For radio waves with wavelengths of centimeters or longer, the accuracy needed is much less than for optical telescopes, because the wavelength of visible light is *much* shorter.
- So radio telescopes can be much bigger than optical telescopes!

The Parkes Radio Telescope in Australia

Radio telescopes in a nutshell

- **Arrays** of radio telescopes electronically connected have much **greater angular resolution** than optical telescopes.
- The VLA (Very Large Array) in New Mexico is an example, with 27 telescopes acting as one telescope 17 miles across.

Radio telescopes in a nutshell

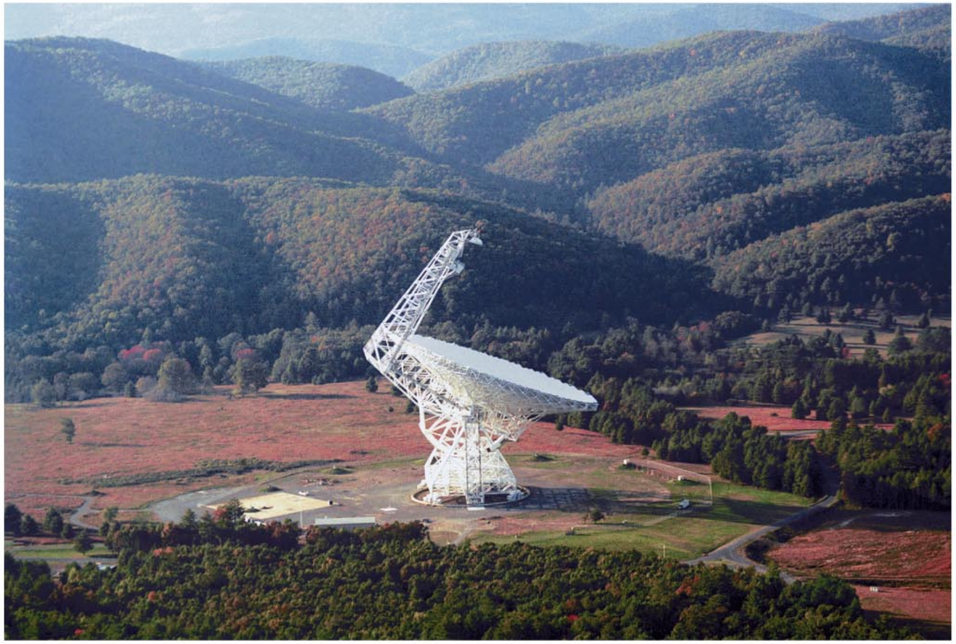
- The greatest angular resolution is obtained by electronically joining radio telescopes on opposite sides of the earth. The electronic technique is called **interferometry**, and it gives resolving power comparable to that of a telescope whose radio dish is the size of the earth. The distance between electronically connected telescopes is called the baseline, and the apparatus is called a VLBI, or very long baseline interferometer.

Radio telescopes:

- **Similar to optical reflecting telescopes**
- **Less sensitive to imperfections due to longer wavelengths – surface has to be smooth on the scale of wavelengths of light observed**
- **Can be made very large**

Green Bank Telescope, 105 m diameter

National Radio Astronomy Observatory, West Virginia



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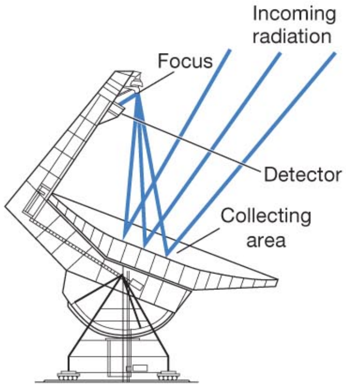
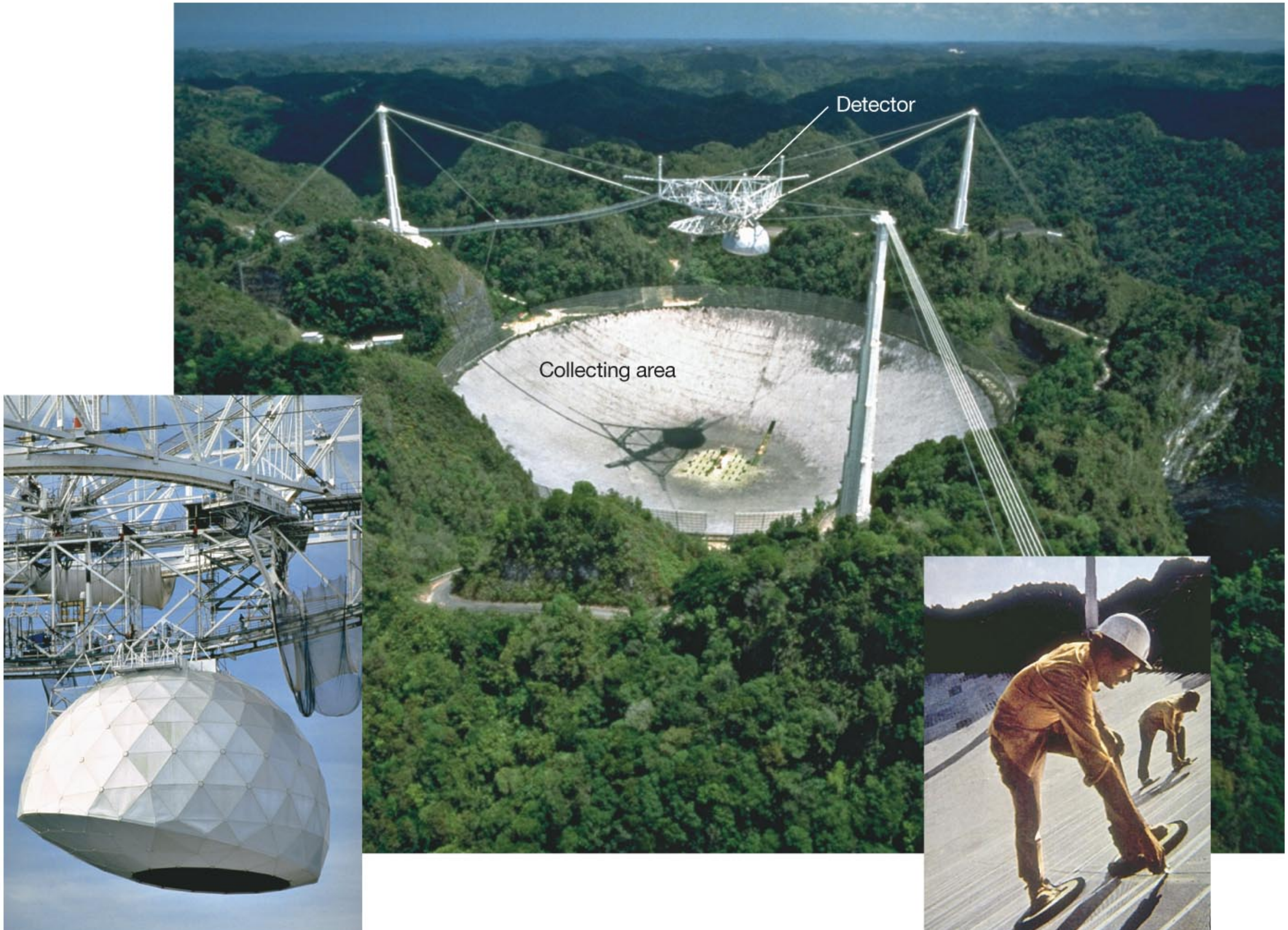


(b)

The Arecibo Radio Telescope: 300 m diameter, Puerto Rico

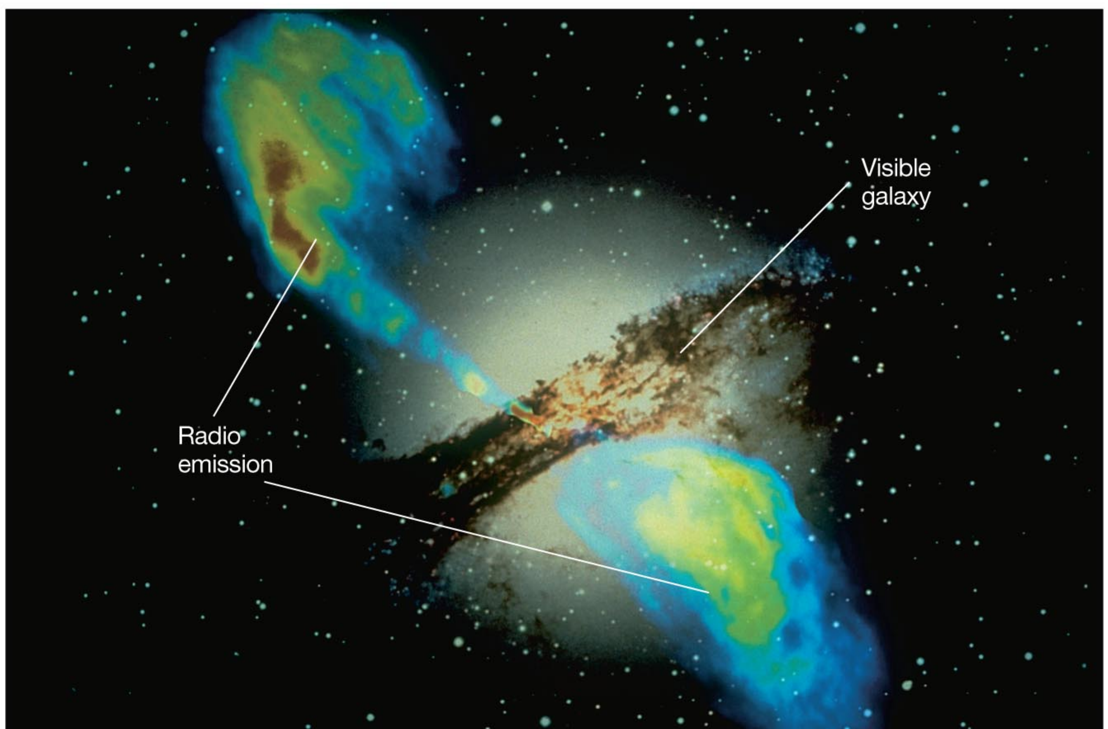
Built in a natural valley – fixed, cannot point at different places in the sky!

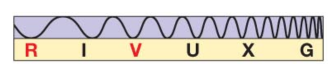
Used for a project involving UWM undergrads, grad students, postdocs, and faculty



Advantages of radio astronomy

- Can observe 24 hours a day
- Clouds, rain, and snow don't interfere (though this depends somewhat on wavelength)
- Observations at an entirely different frequency; get totally different information





Longer wavelength means poorer angular resolution

- Atmospheric blurring isn't an issue in radio
- The *diffraction limit* is
  - Ultimate limit in angular resolution comes from **diffraction**, the spreading of light as it passes a corner or opening

$$\text{angular resolution (arc seconds)} = 0.25\,\frac{\text{wavelength }(\mu\text{m})}{\text{mirror diameter (m)}}$$

  - Longer wavelength: poorer resolution
  - Larger telescope: better resolution

We're observing 0.2 m radio waves with the Green Bank Telescope. What's our angular resolution?

$$\text{angular resolution (arc seconds)} = 0.25 \frac{\text{wavelength } (\mu\text{m})}{\text{mirror diameter (m)}}$$

What's our wavelength? 1 μm = 10^{-6} m, so 0.2 m = 2 x 10^{5} μm
What's the diameter of the GBT? 105 m

$$\text{angular resolution (arc seconds)} = 0.25 \frac{2 \times 10^{5}}{105}$$

$$= 476 \text{ arc seconds}$$

What does this mean?
If two objects are closer than about 480 arc seconds on the sky, we won't be able to separate them.
How far apart is that?

- The full moon is about half a degree in angular size
- 1 degree = 60 arc minutes and 1 arc minute = 60 arc seconds, so 1 degree is 3600 arc seconds
- So our resolution of about 480 arc seconds is about a quarter of the full moon
- Not great, if we want to look at small, distant things!

So what do we do? We can combine the light from several telescopes, so that they act like a big telescope with diameter equal to the distance between them!

The Very Large Array

(a)

(b)

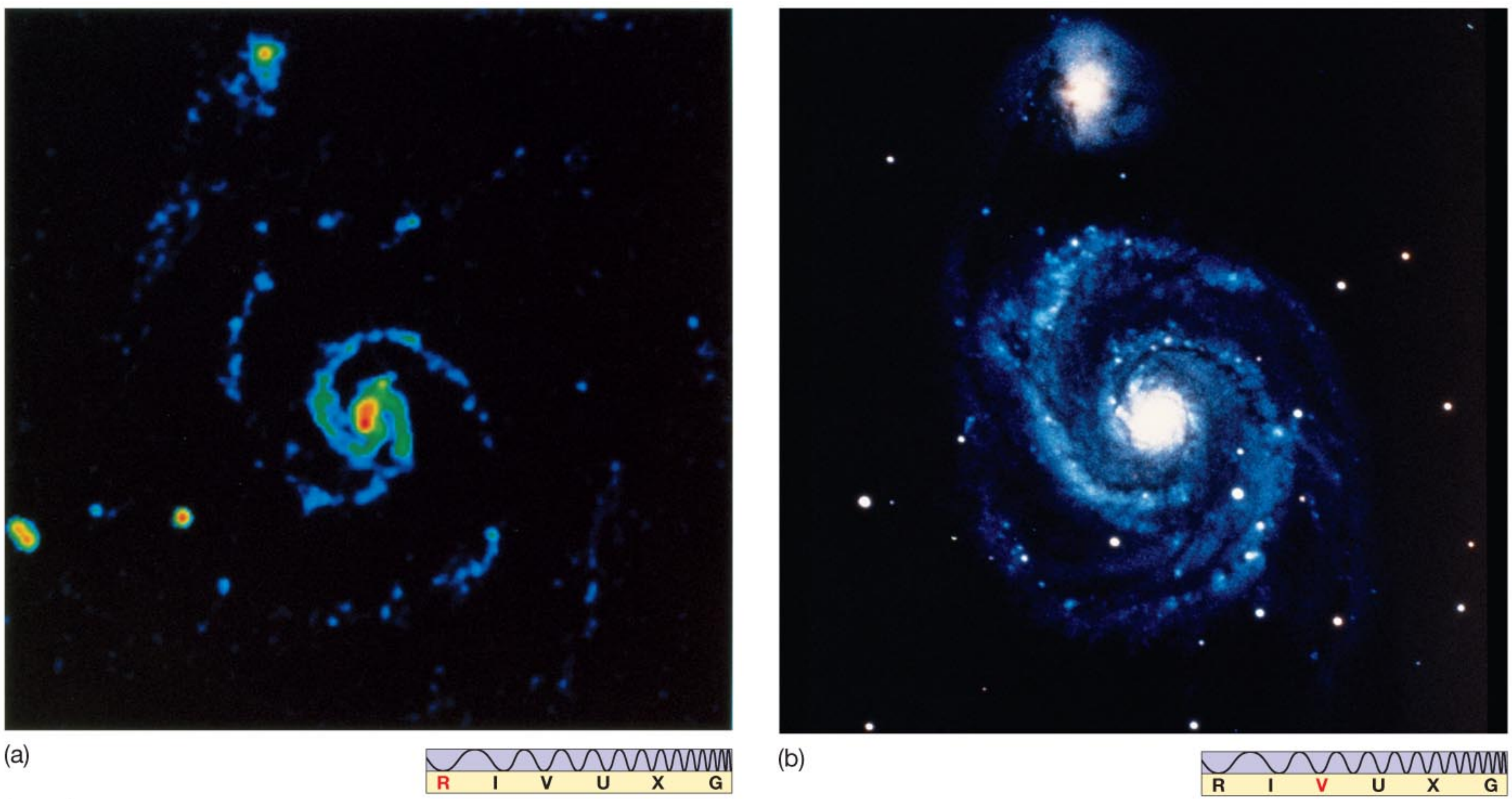
Interferometry

• Combines information from several widely spread radio telescopes as if it came from a single dish.

• Resolution will be that of dish whose diameter = largest separation between dishes.

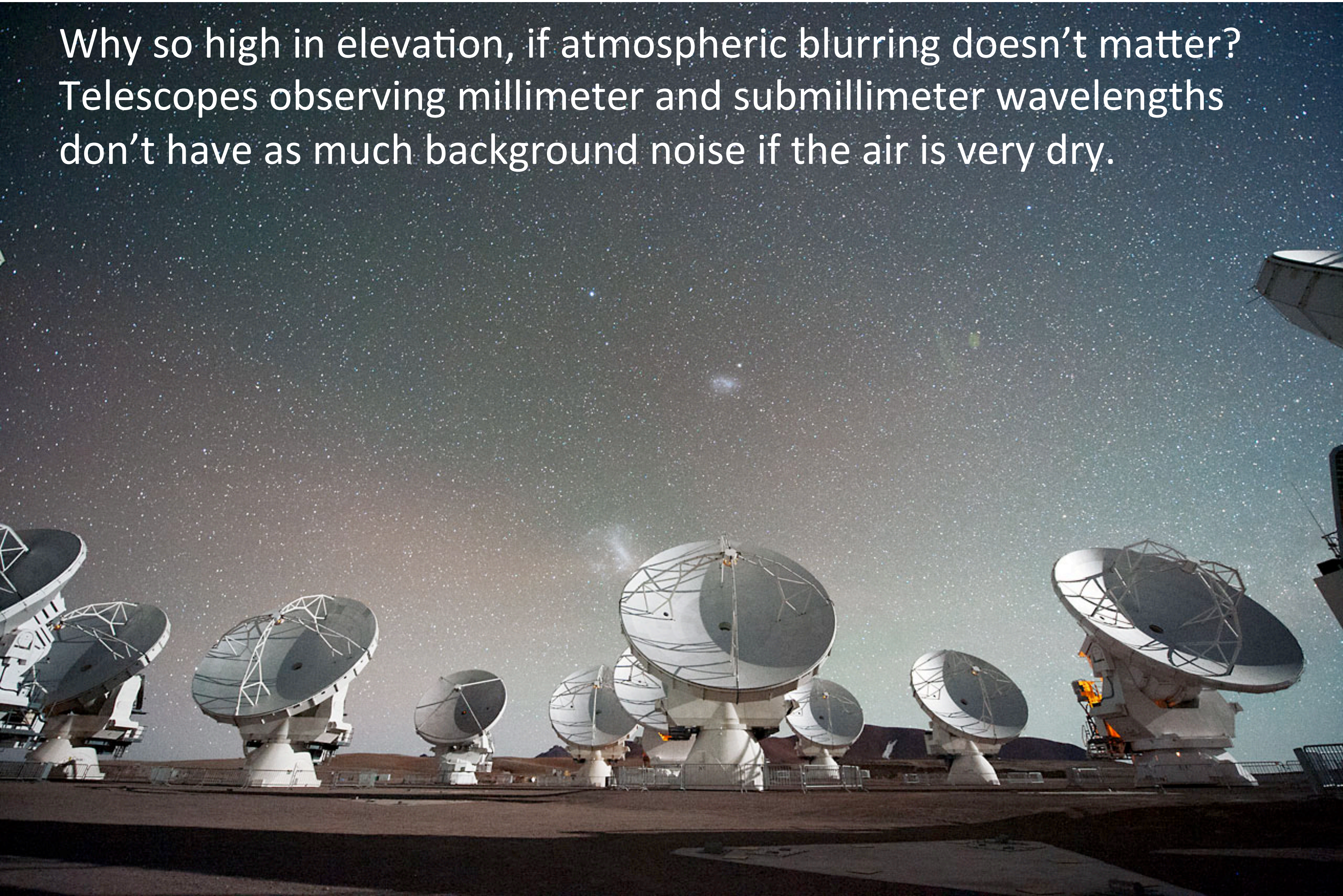
Very Long Baseline Interferometry (VLBI): resolution of a telescope with the size of the Earth!

With interferometry we can get radio images whose resolution is close to optical.



The Atacama Large Millimeter Array, currently under construction in Chile’s Atacama desert, elevation 16,600 ft

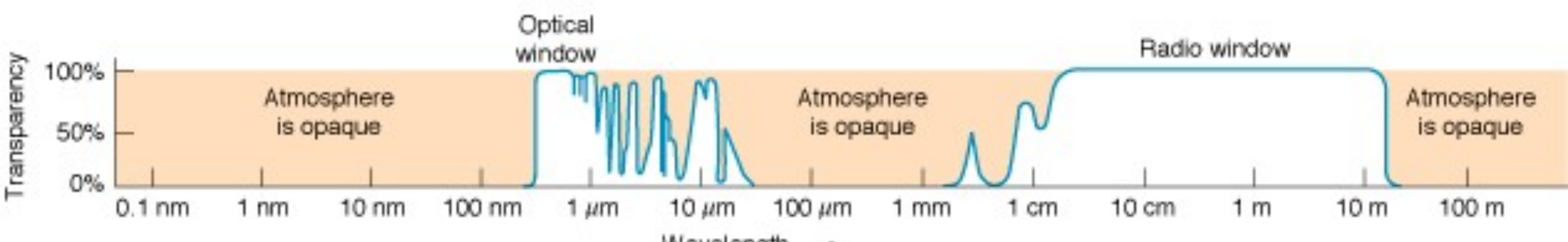
Why so high in elevation, if atmospheric blurring doesn’t matter? Telescopes observing millimeter and submillimeter wavelengths don’t have as much background noise if the air is very dry.



There are still other wavelengths of light we would like to observe!

Optical and radio wavelengths can be seen from the ground.

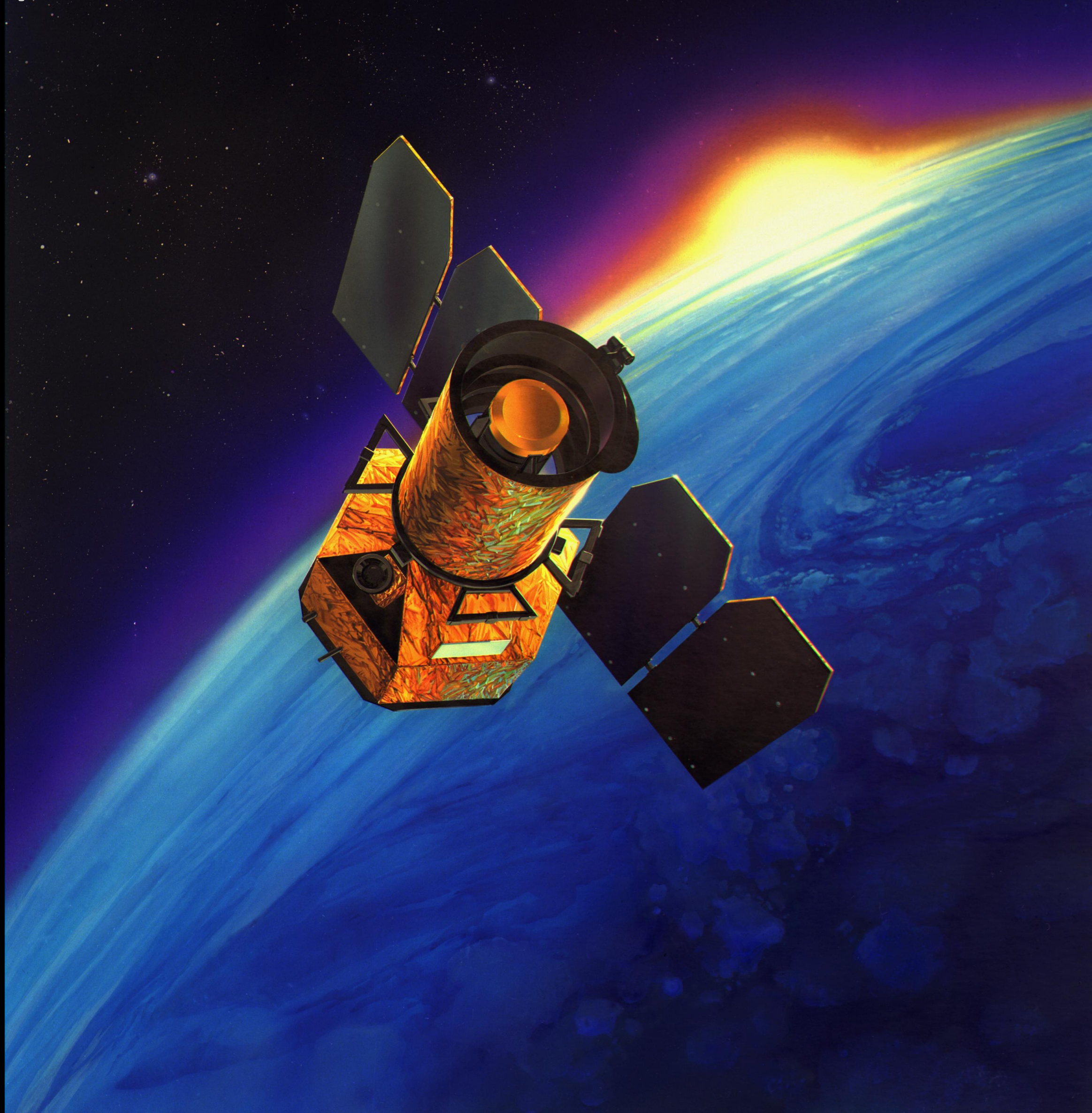
For γ-rays, X-rays, most ultraviolet and most infrared light, one uses satellite telescopes.



γ-rays X-rays UV visible infrared microwave RADIO

GALEX: Galaxy Evolution Explorer

Space-based UV telescope



GALEX Galaxy Evolution Explorer

Ultraviolet + Visible/GALEX + SDSS

Visible/SDSS

Ultraviolet Tail of Galaxy IC 3418

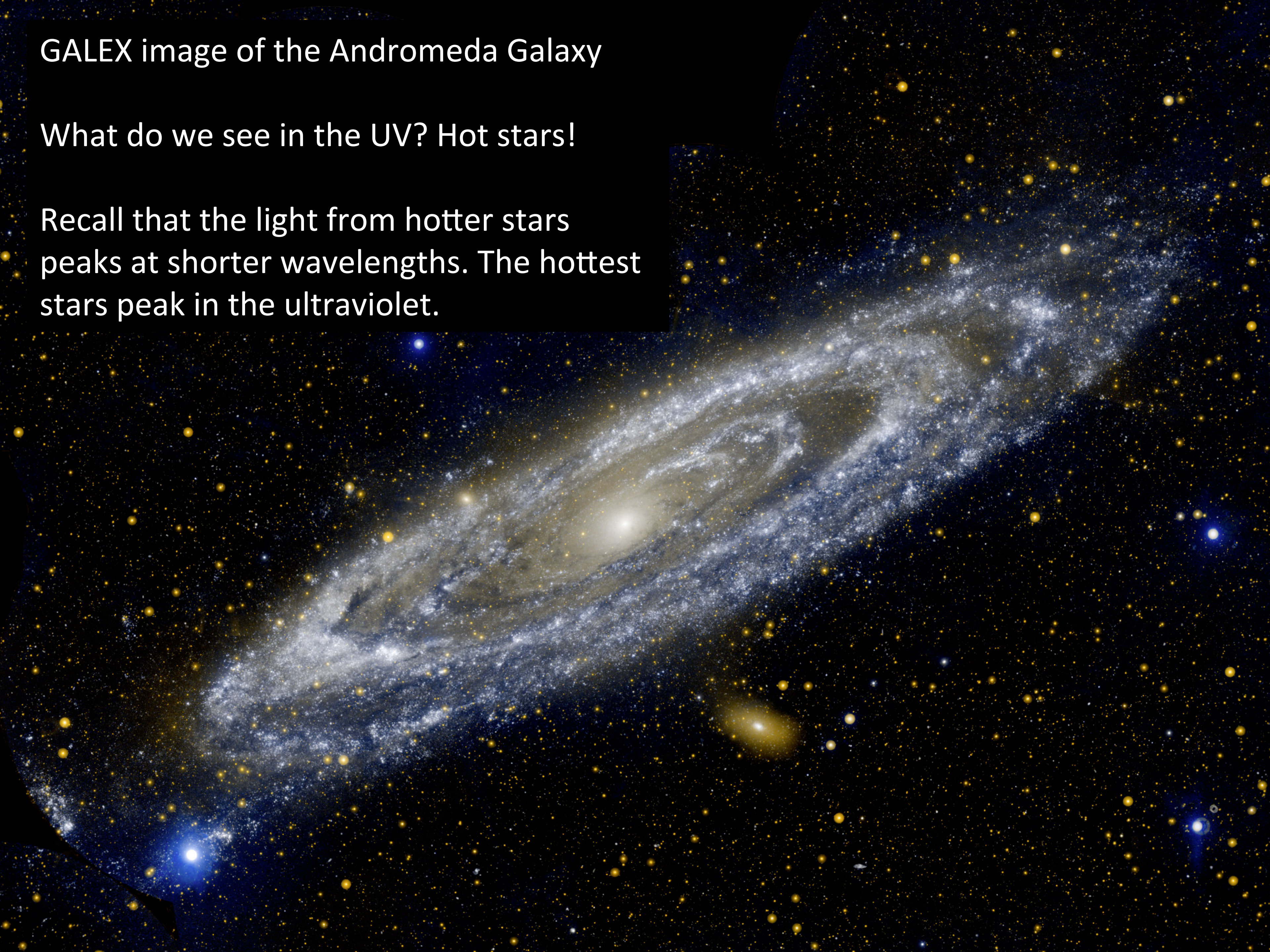
NASA/JPL-Caltech

GALEX • FUV • NUV
Sloan Digital Sky Survey

GALEX image of the Andromeda Galaxy

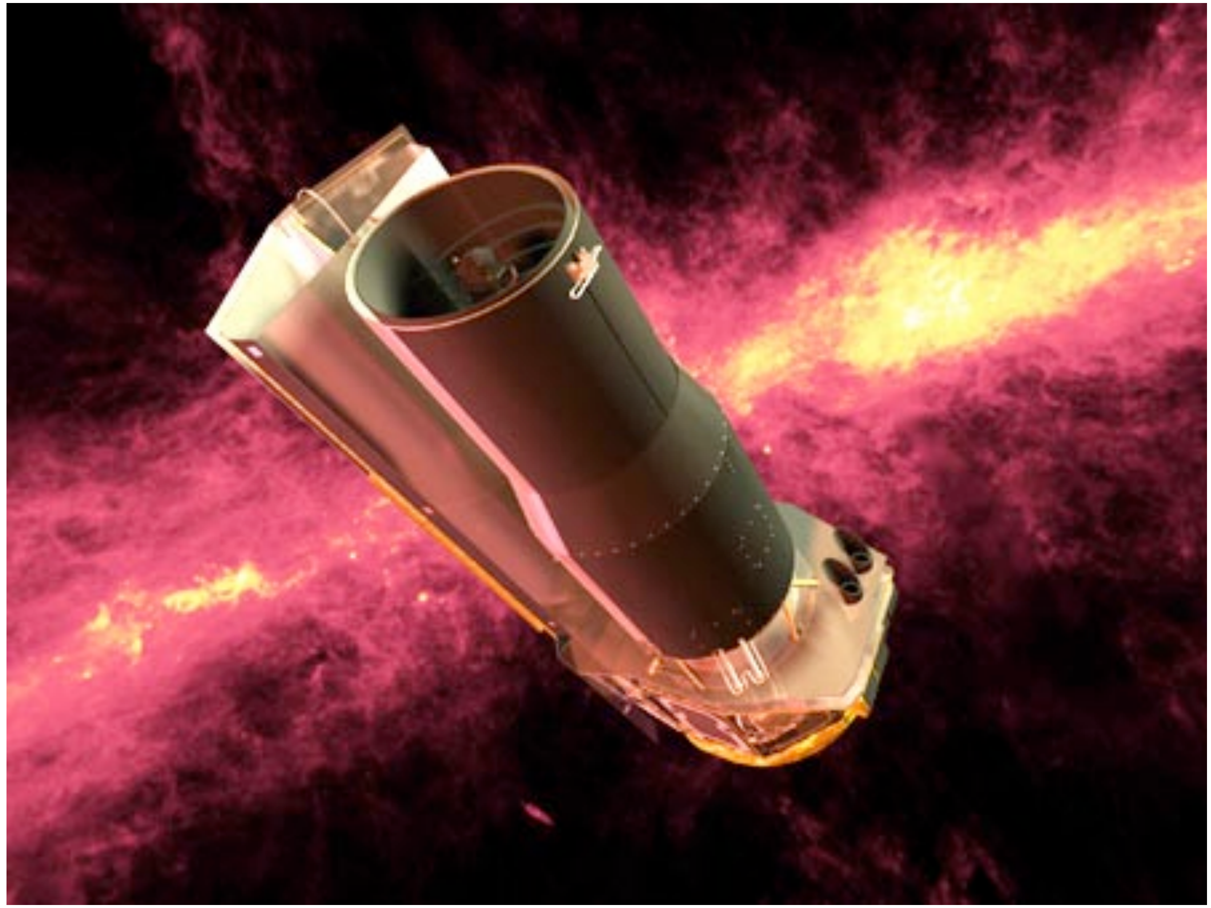
What do we see in the UV? Hot stars!

Recall that the light from hotter stars peaks at shorter wavelengths. The hottest stars peak in the ultraviolet.



The **Spitzer Space Telescope**, an infrared telescope in space

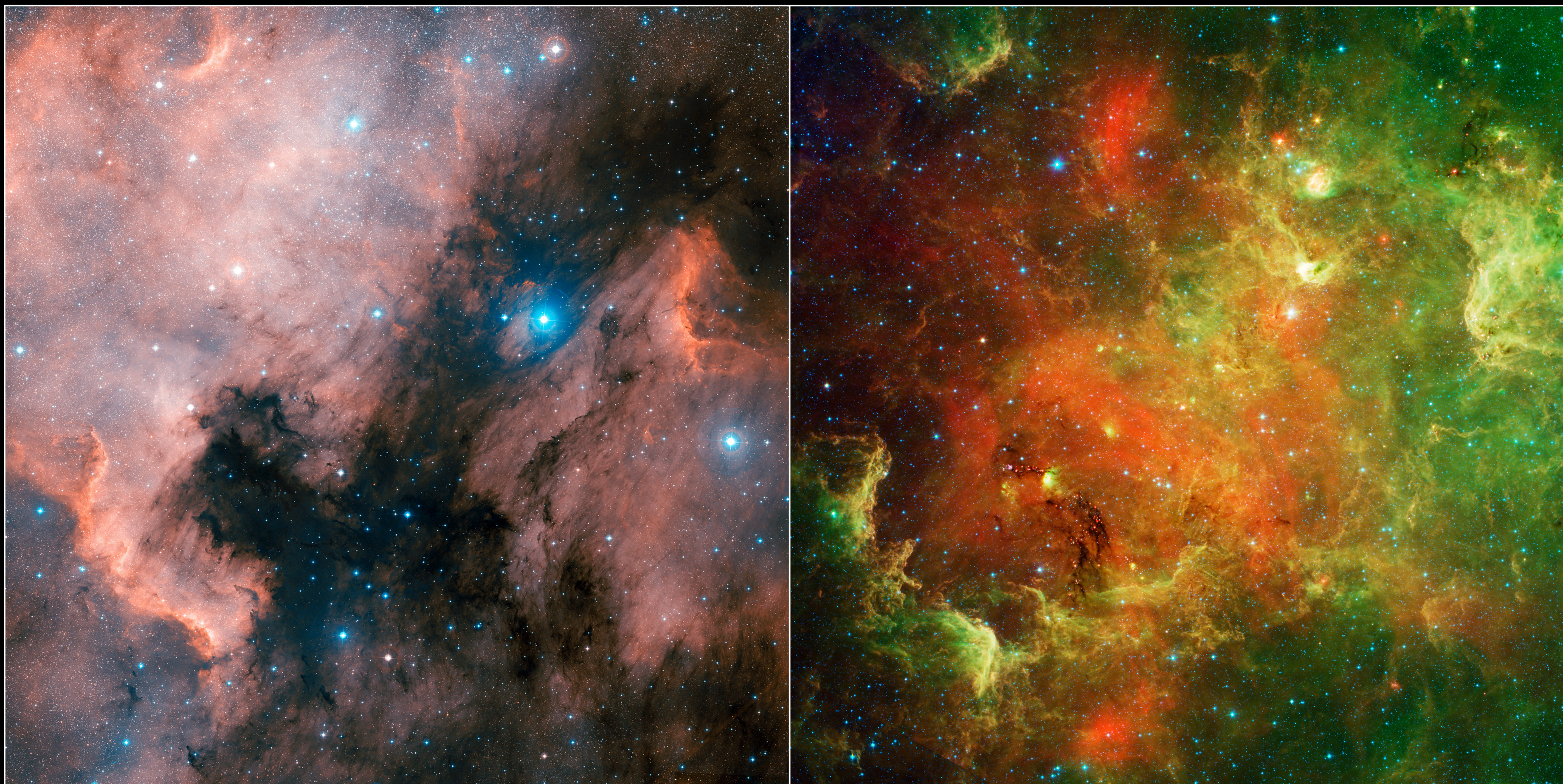
Everything emits radiation because of its temperature. Cold things emit in the infrared, so to observe in the infrared our telescope must be very very cold, or else it will be much brighter than what we're trying to look at!



Cooled to 4 K by liquid helium (until it ran out) – must be very very cold to keep thermal background low

Visible Light (DSS/D. De Martin)

Infrared Light



North American Nebula Comparison

NASA / JPL-Caltech / L. Rebull (SSC/Caltech)

Spitzer Space Telescope • IRAC • MIPS

ssc2011-02b

Young stars in the Orion Nebula,
from the Spitzer Space Telescope

Interstellar gas clouds, where stars form, have temperatures of 10 – 100 K. What wavelengths do we need to look at to see them?

$$\lambda = \frac{3 \times 10^6}{T}\ \mathrm{nm}$$

About 3000 to 30,000 nm, in the infrared.

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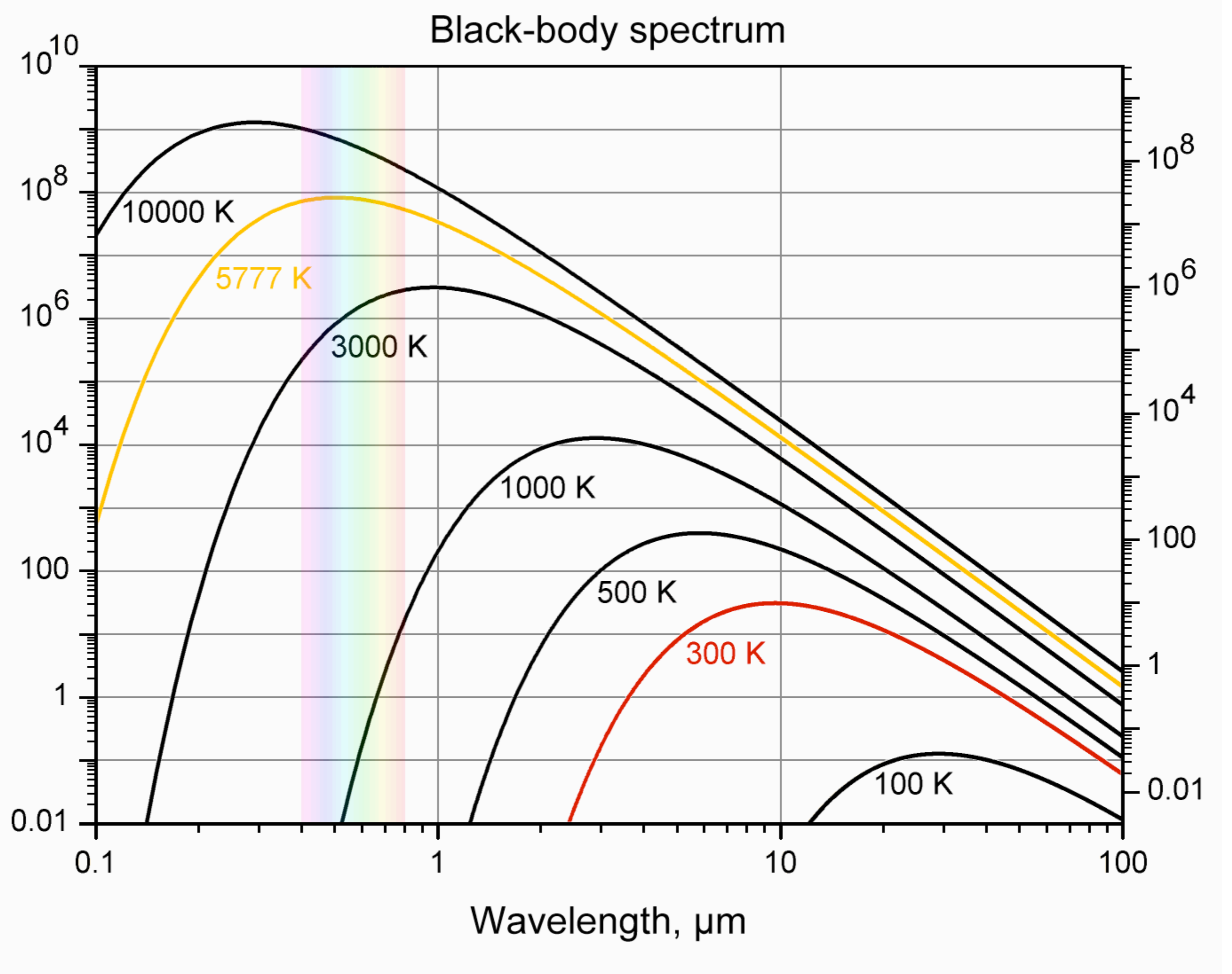
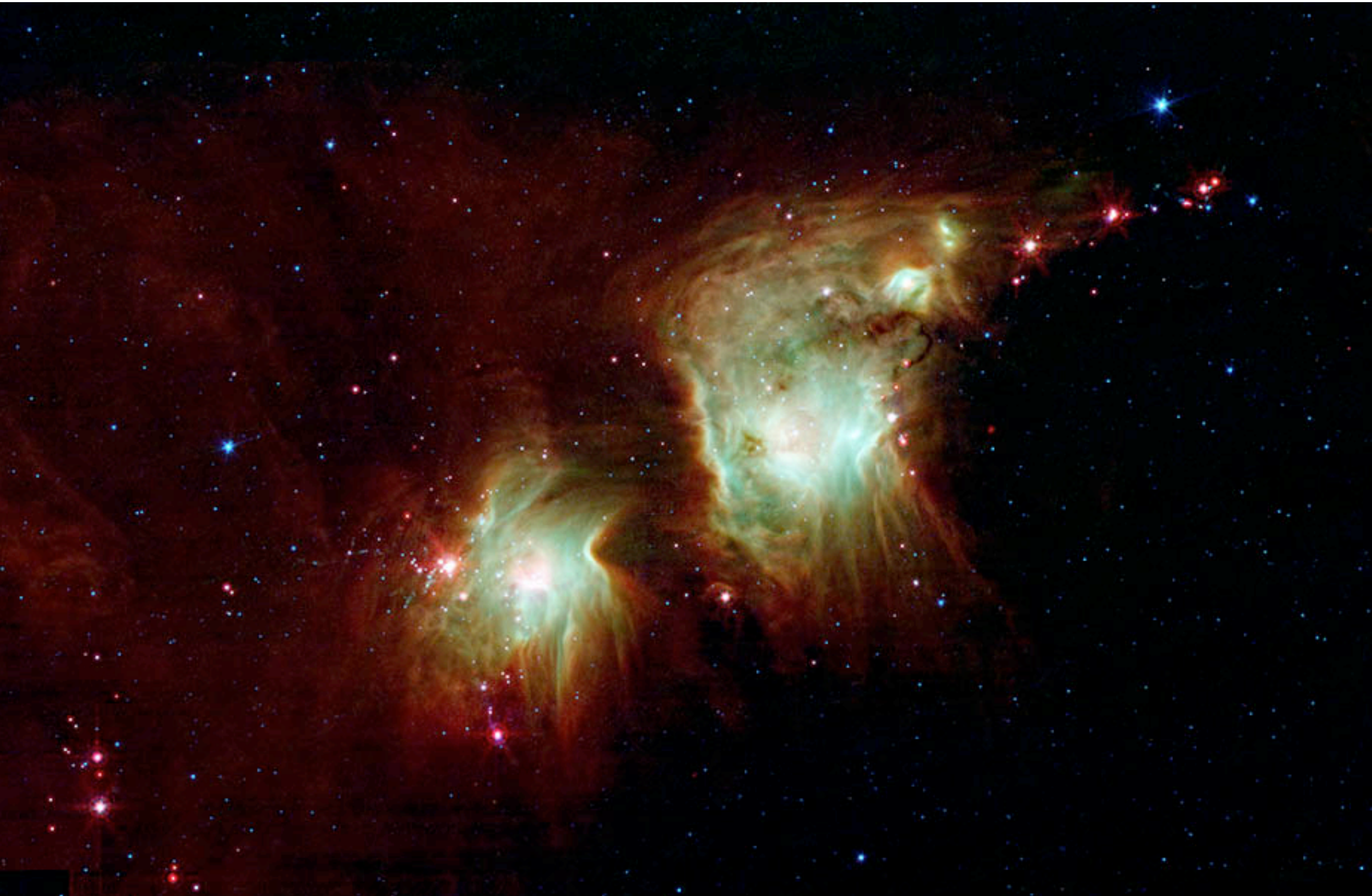


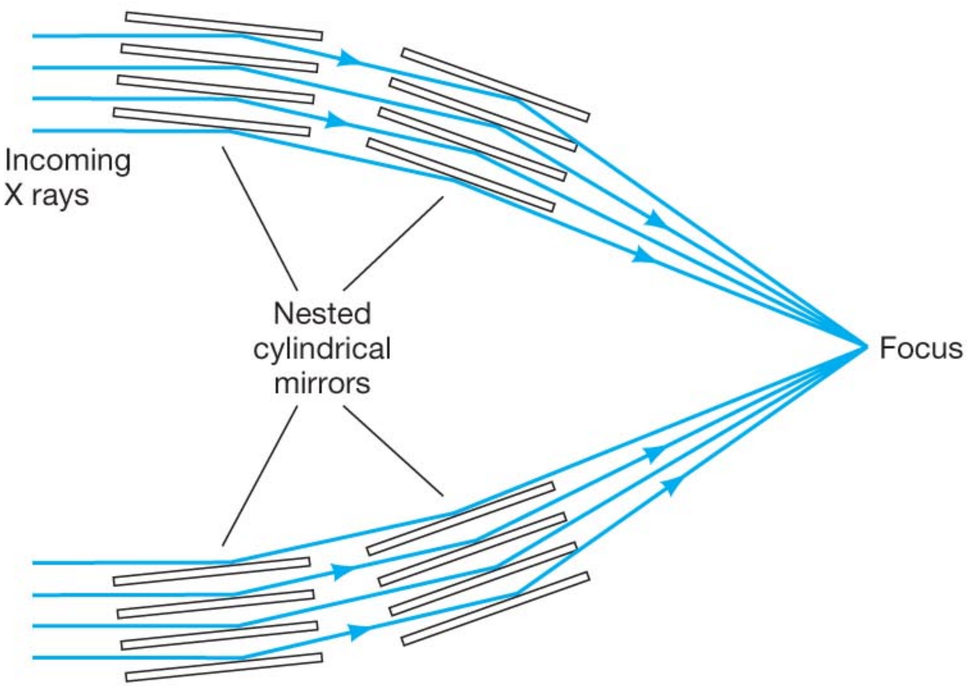
Stars forming in the Orion Nebula, from the Spitzer Space Telescope



What about shorter wavelengths?

X-rays and gamma rays will not reflect off mirrors as other wavelengths do; need new techniques.

X-rays will reflect at a very shallow angle, and can therefore be focused.



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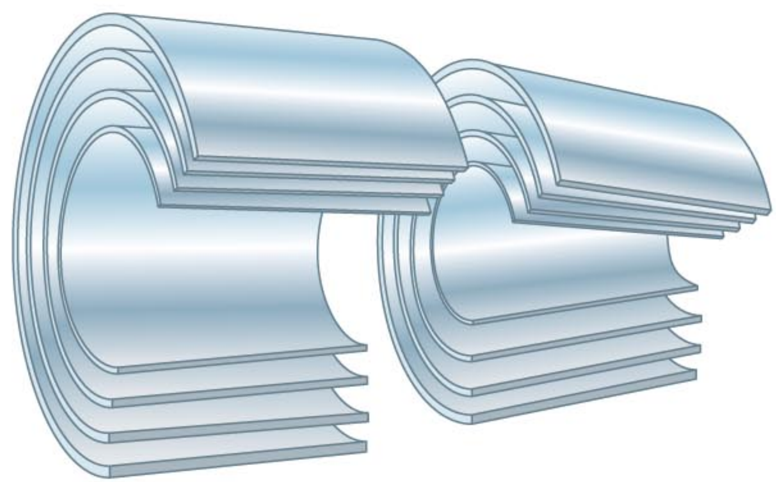
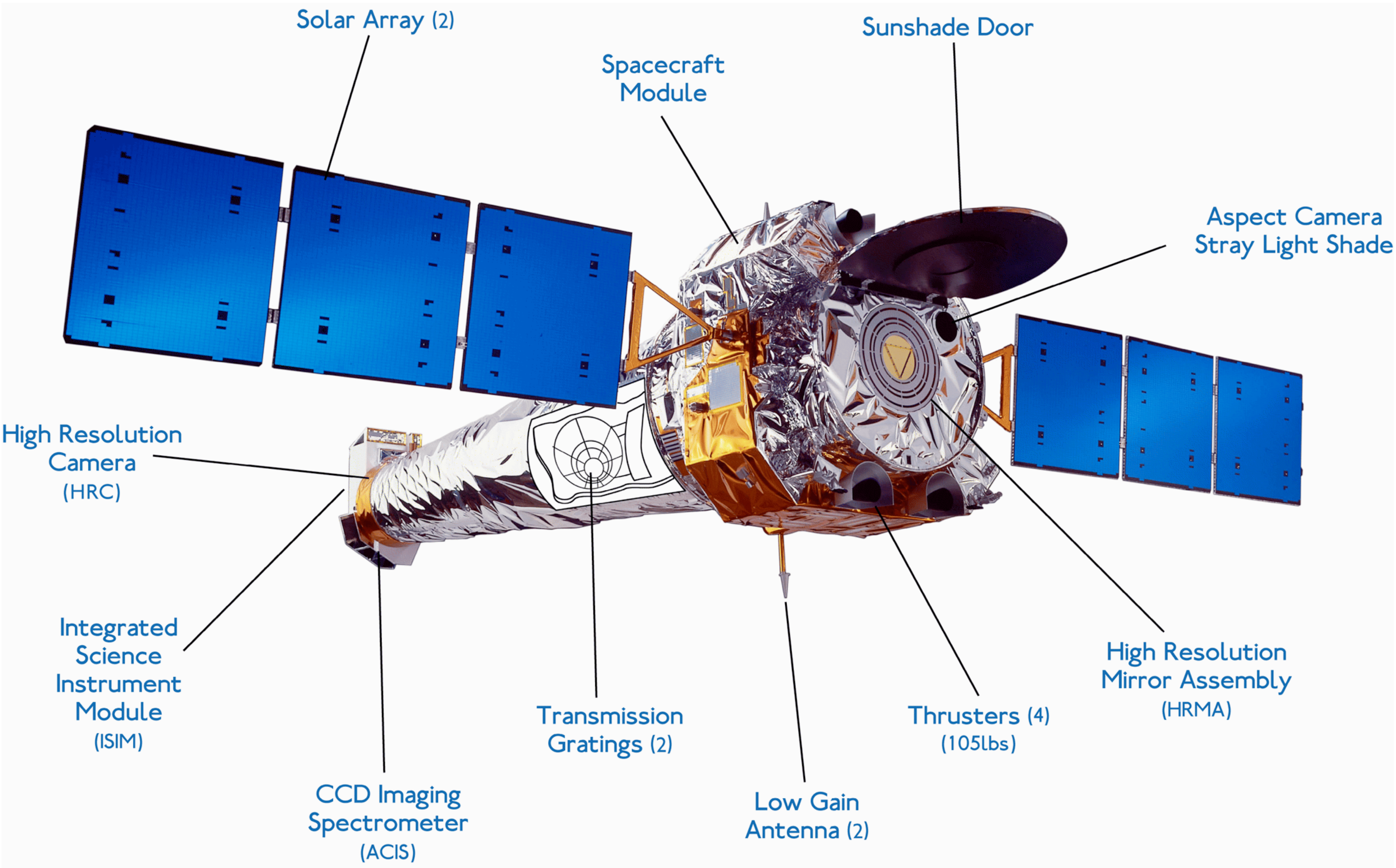
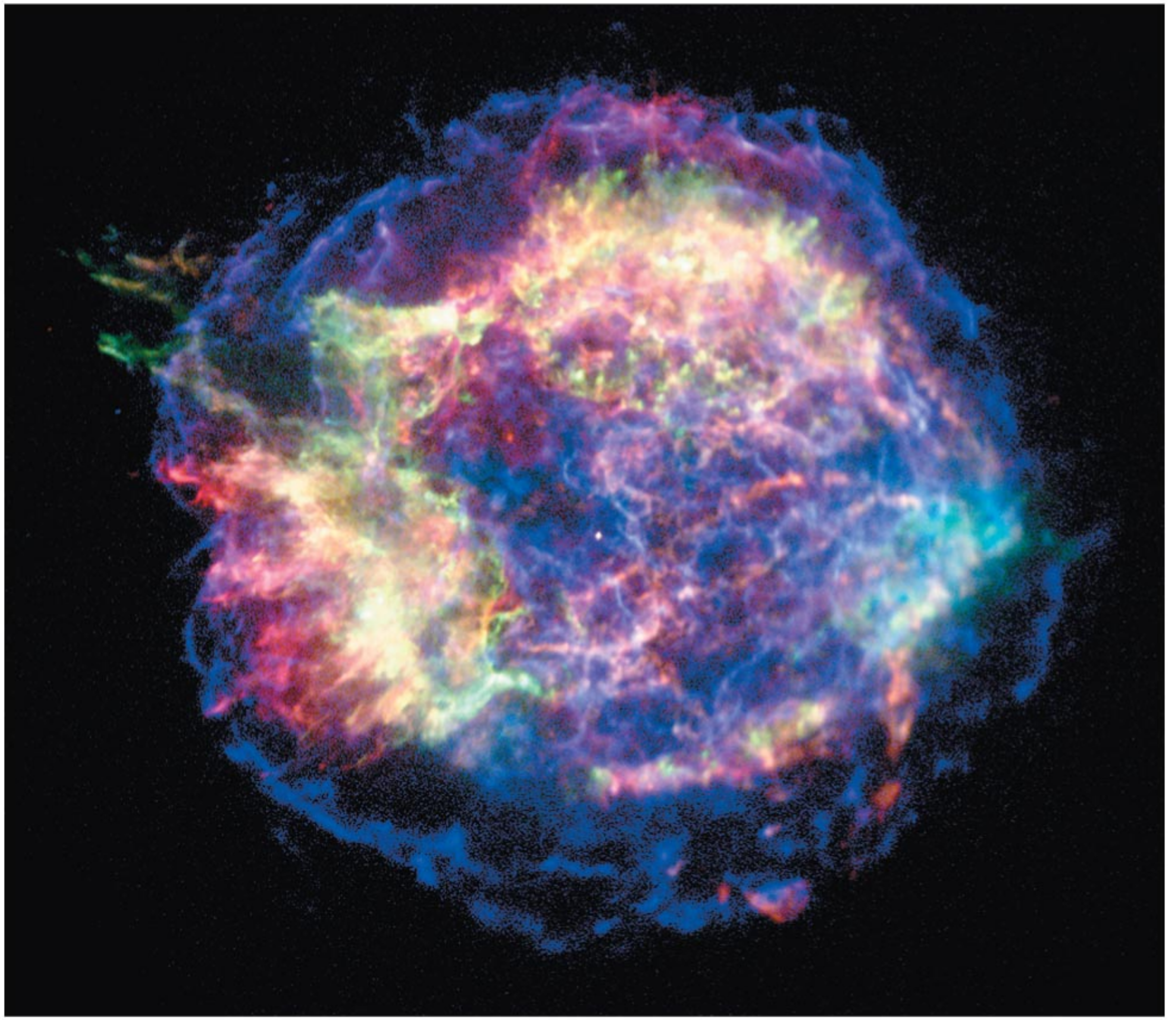


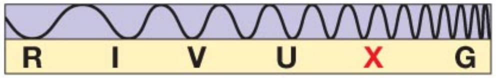
(b)

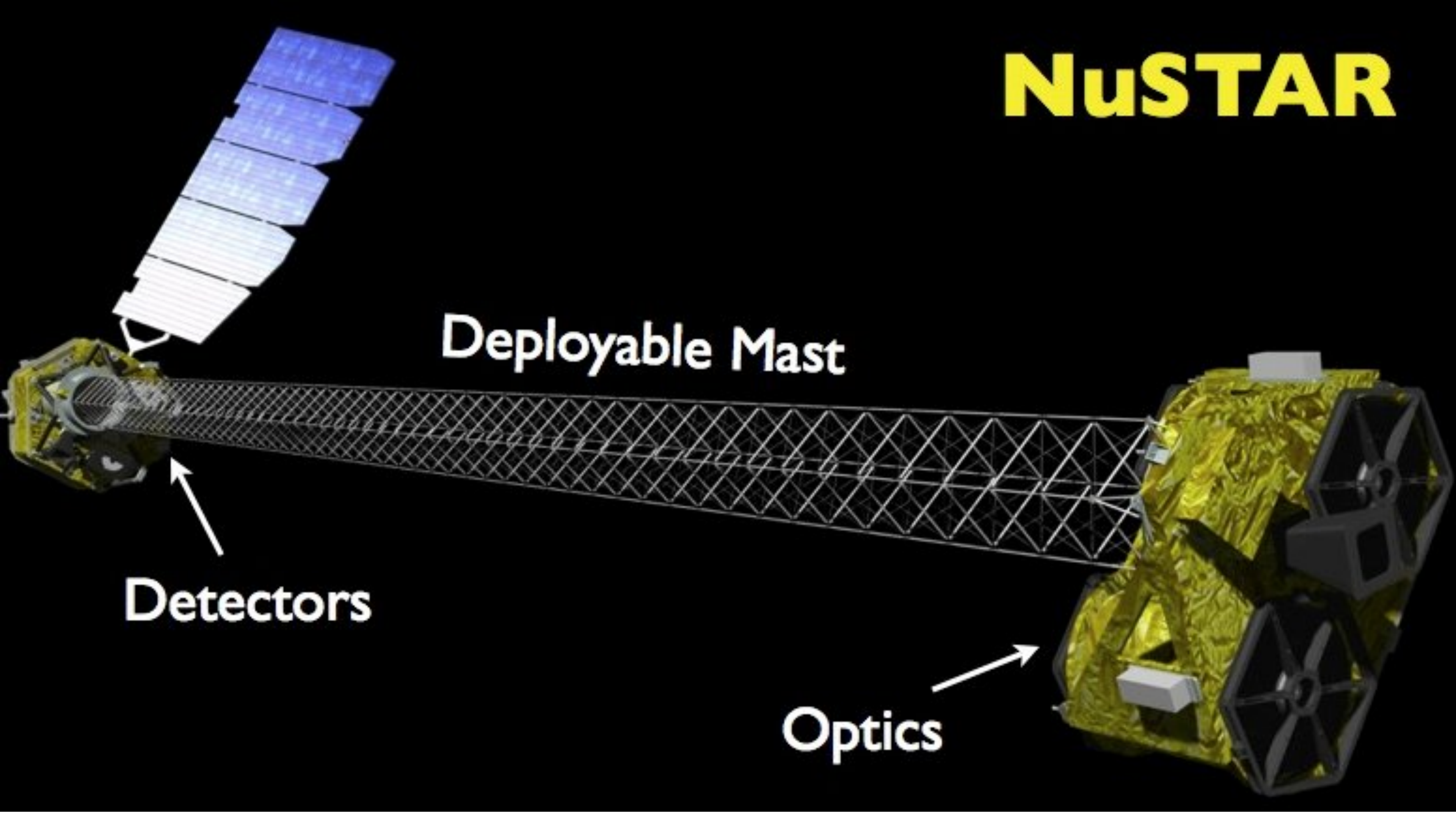
The Chandra X-ray Observatory



X-ray image of supernova remnant Cassiopeia A

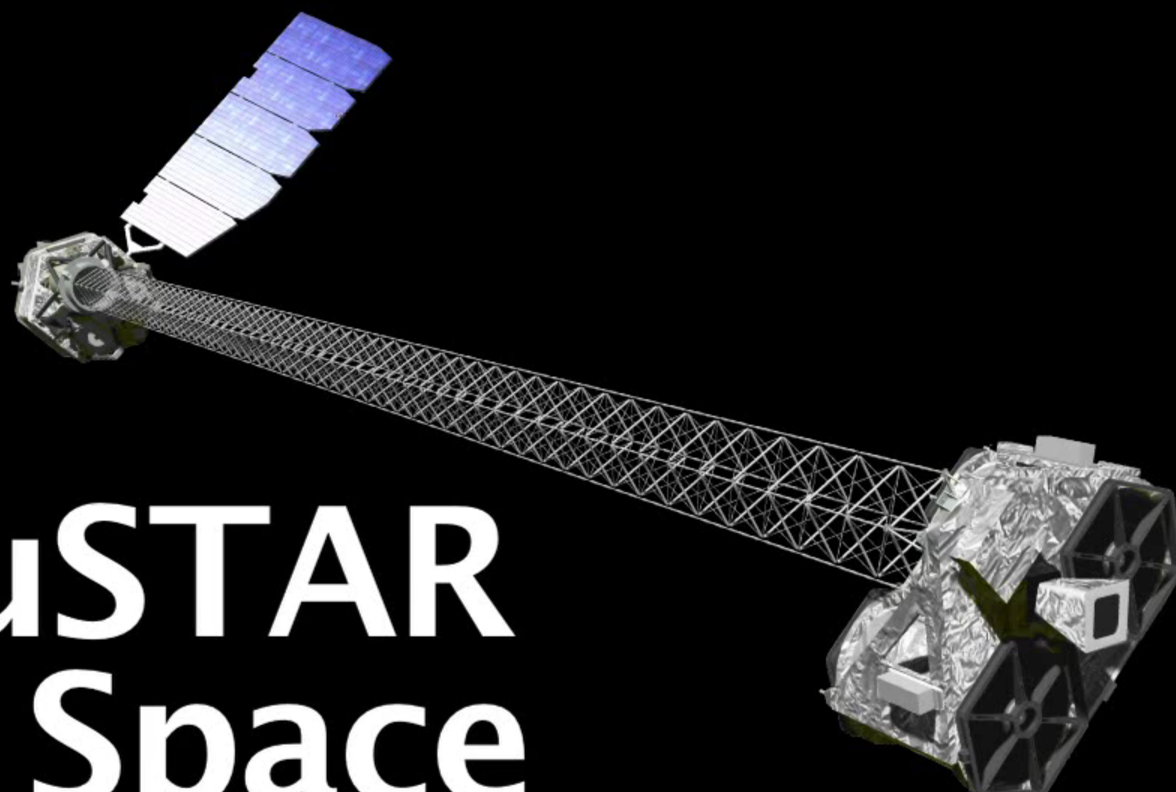




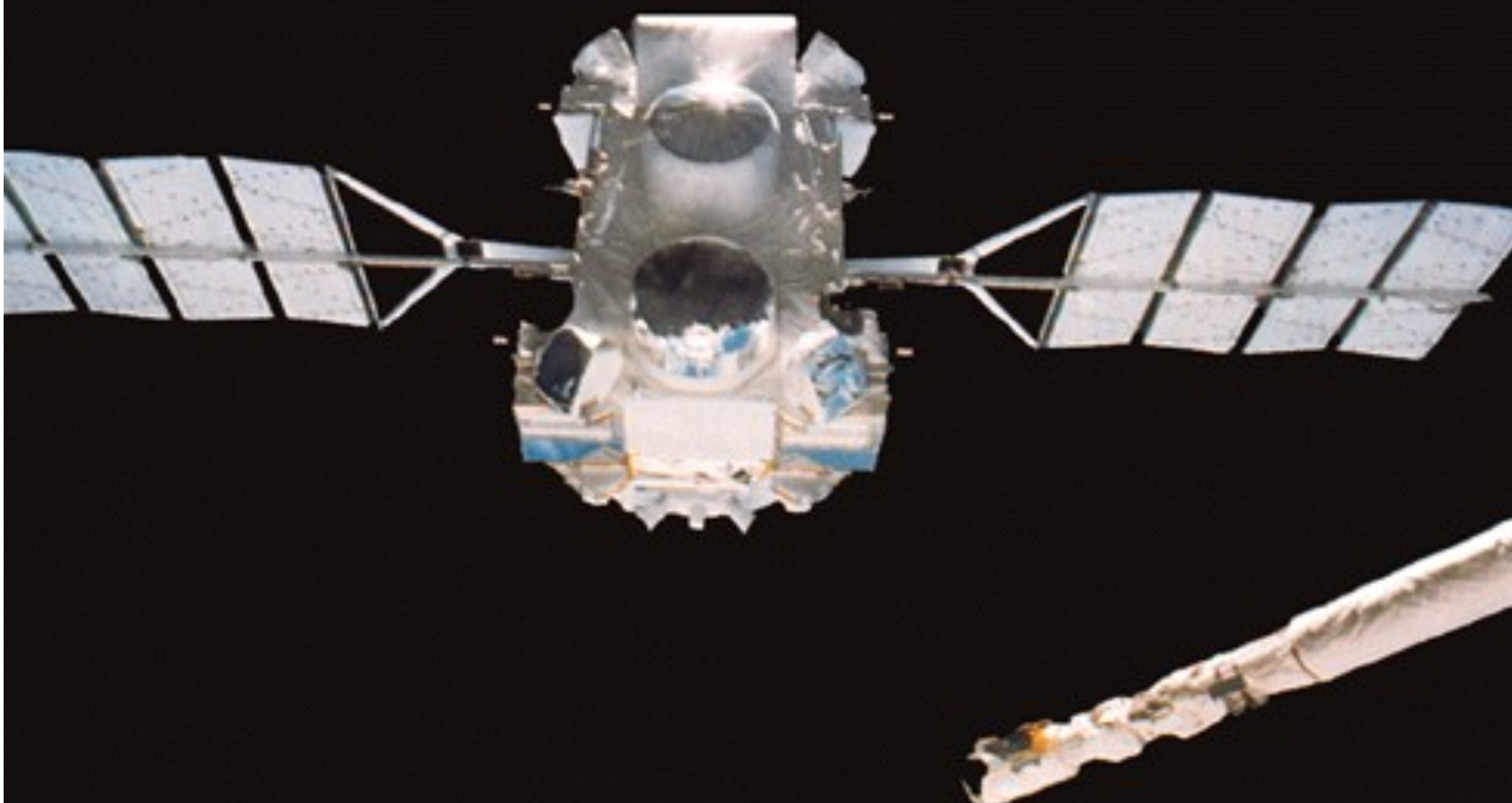


NuSTAR: new X-ray satellite that observes higher energy X-rays. Uses extending mast so deflection angle of high energy X-rays can be very small.

NuSTAR in Space



The Compton
γ-ray observatory



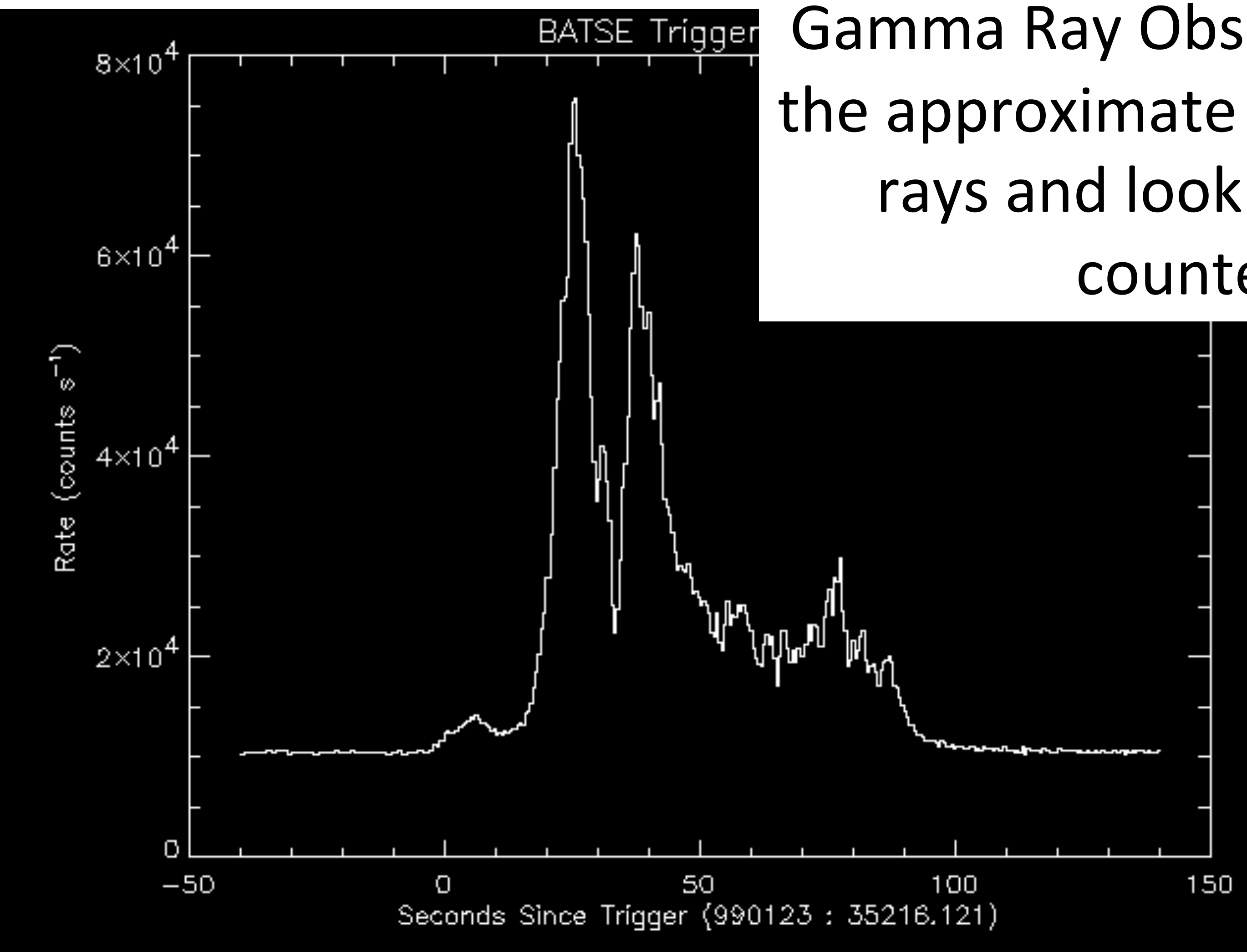
Arm of the shuttle from which the Compton satellite was released

The Fermi Gamma Ray Telescope in Earth orbit

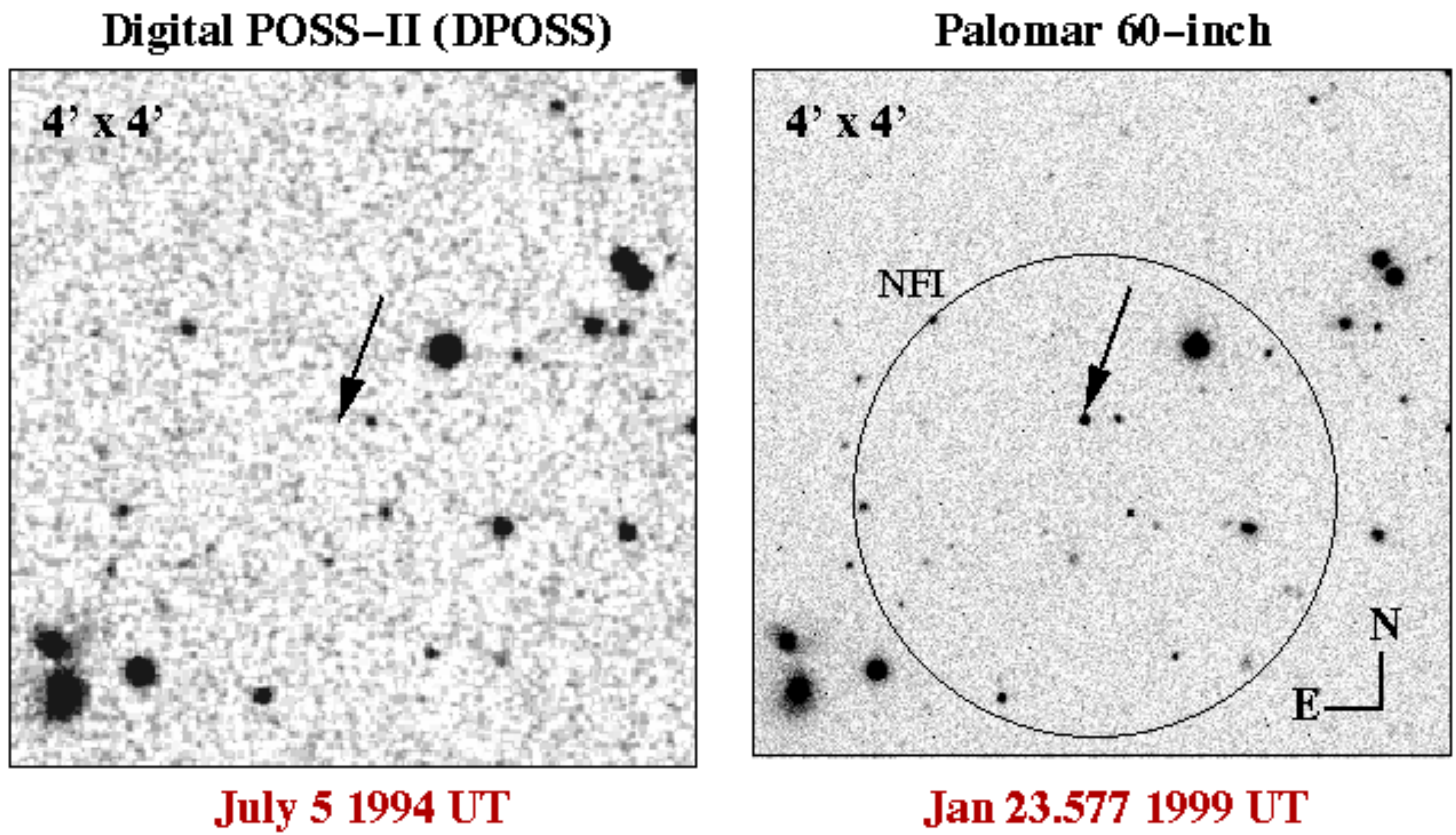
Fermi Gamma-ray Space Telescope

Gamma rays can't be focused.
We just put a detector in
space and wait for them.

Gamma Ray Bursts are some of the most energetic events in the Universe. They are detected in space, here by the Compton Gamma Ray Observatory. We get the approximate position of the γ-rays and look for an optical counterpart.



The dark spot in the photograph on the right is the optical afterglow of a burst of γ-rays from one of the Universe's most energetic events, with 100 times more energy than the Sun emits in its lifetime. And it is released in 10 seconds.



Why do we put telescopes in space?

A — To see wavelengths of light we can't see from the ground

B — To continuously observe for more than 24 hours, avoiding sunlight

C — To avoid the blurring effects of the atmosphere

D — All of the above

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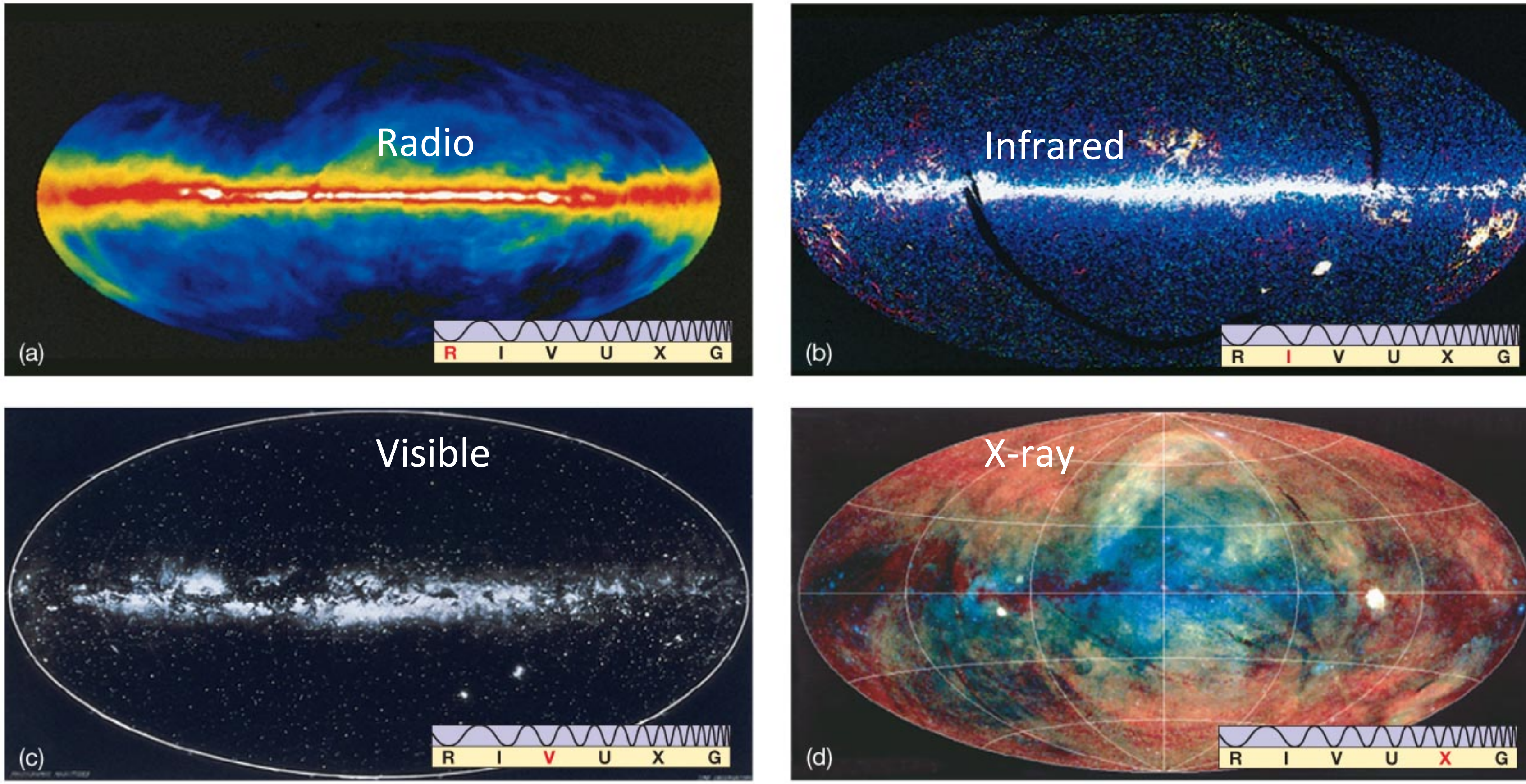

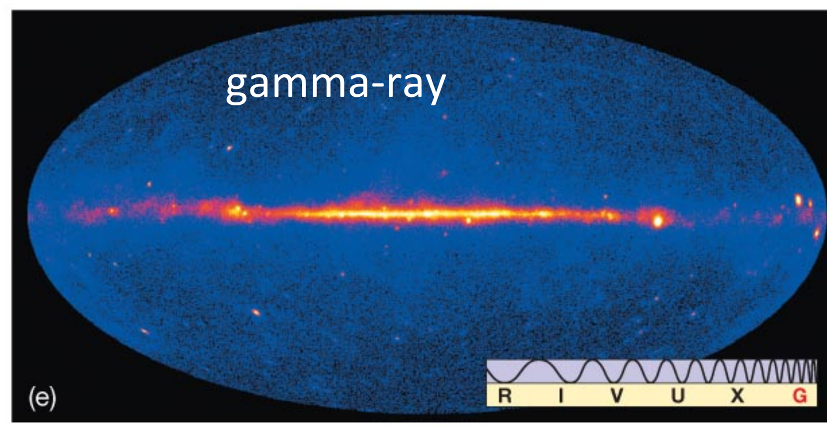

Much can be learned from observing the same astronomical object at many wavelengths. Here, the Milky Way.